Chapter 11 Vapor Deposition Hall Elements and Their Characteristics

(Ichiro Shibasaki)

Section 4. Fabrication of Hall elements, InSb vacuum deposition method, and semiconductor characteristics

Hall elements produced by vacuum deposition are not limited to InSb, but the most used is the InSb Hall element. Here, I would like to describe the basic process of InSb deposition Hall elements and vacuum deposition.

When preparing Hall elements by vacuum deposition method, as described in Section 2, the fabrication of InSb deposition thin films with high electron mobility becomes a problem. Next, the thin film is photo-etched to form a microscopic Hall element pattern, and the Hall element is fabricated through processes such as electrode attachment, lead bonding, and resin molding. Fig.7 shows the flow chart of the process of making such a Hall element.

In the vacuum deposition process, the thin film properties of InSb, which determines the basic characteristics of the Hall element, are determined, and in the etching process, the input/output resistance and rated characteristics of the Hall element are determined according to the design values, and in the subsequent processes, the lead wire, package, inspection, etc. of the Hall element are attached. Except for the vacuum deposition process, it is a manufacturing process similar to the manufacturing process of general semiconductor devices, and it is not a process specific to Hall devices, so details will be omitted.

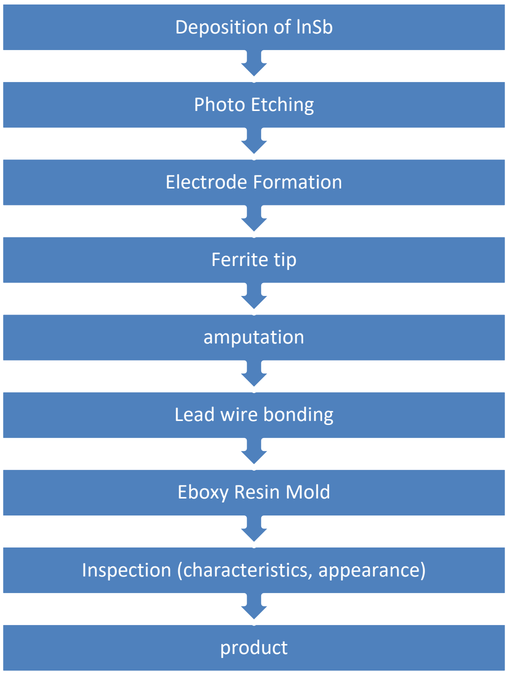

Fig.7 Example of manufacturing process of InSb Hall element.

Now, the biggest problem when fabricating Hall elements of InSb by vacuum deposition is how to obtain thin films with high electron mobility. A vacuum deposition method based on several slightly different ideas has been proposed as an industrial vacuum deposition method to obtain InSb deposition films with a film thickness of less than 1 μm and an electron mobility of μ_H of 10,000 $cm^2/V\cdot$ sec or more. By selecting several conditions in each method, it is possible to produce electron mobility μ_H more than 10,000 $cm^2/V\cdot$ sec. Also, from a laboratory point of view, this is not the case.

Now, the reason why InSb deposition is particularly difficult is the large difference in vapor pressure between In and Sb. Therefore, when InSb is deposited in a normal vacuum, the atomic ratio of In and Sb in the thin film of InSb deposited on the substrate is 1:1, that is, the so-called stoichiometric composition is not obtained, and the semiconductor properties of the formed thin film are extremely reduced. Another problem is that the thin films produced by deposition are polycrystalline, and the size of these crystal particles greatly affects the characteristics of semiconductors, but the state of these crystal particles changes greatly depending on the deposition conditions. Therefore, if these factors that affect the characteristics of semiconductors are not properly controlled, good properties of InSb deposition films cannot be obtained.

Fig.8 shows the internal structure of a simple InSb deposition machine. In general, the conditions for the deposition of InSb are heated and evaporated at the 10^{-6} Torr range, and at the same time, a thin film of InSb is deposited on the heated deposition substrate that is set on the top of the opposite direction. However, when deposition is performed in this way, more Sb atoms with high vapor pressure evaporate in the early stage of deposition than the evaporation source, and the residual In mainly evaporates in the later stage. On the other hand, on the substrate, the re-evaporation of Sb atoms, which have an overwhelmingly high vapor pressure, is large (the attachment probability of Sb atoms is smaller than that of In atoms).
As a result, the formed vapor film has more In atoms than Sb atoms, and the stoichiometry ratio is deviated. Furthermore, the ratio of In to Sb atoms changes in the direction of film thickness. The composition near the substrate is close to 1:1, and on the surface, there is a lot of In. This makes it difficult to obtain thin films with high electron mobility.

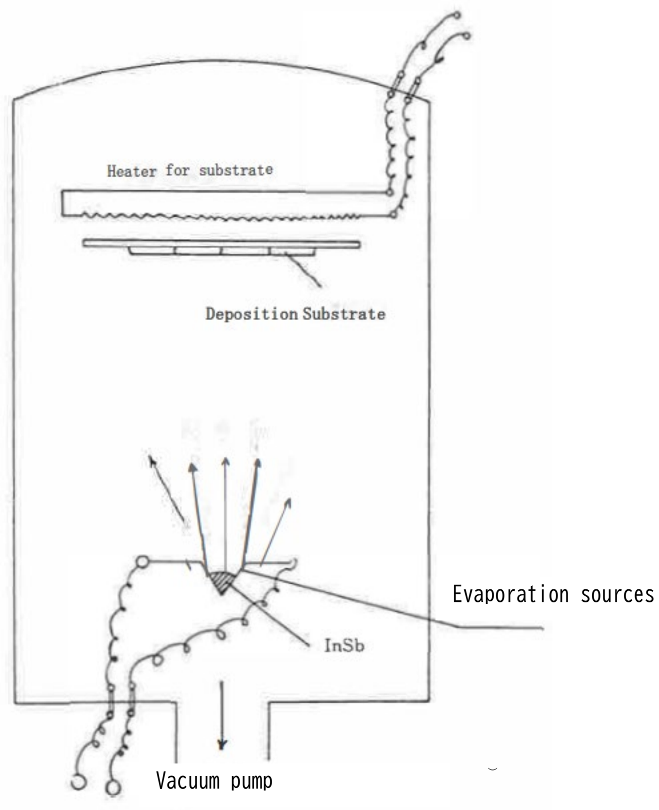

Fig.8 Structure of vacuum deposition machine

As a means to solve this irrational surface, a method has been proposed to control the temperature of the substrate at the optimal temperature for crystallization in order to evaporate In and Sb by putting it in a separate evaporation source, controlling the temperature of the evaporation source separately, so that the adhesion probability of In and Sb on the substrate is the same, and forming a deposition film with high electron mobility. This is a deposition method called the three-temperature treatment method. Fig.9 shows an example of Gunter's apparatus that proposed this method2). Of course, even without this equipment, the three-temperature treatment method is possible with a deposition machine with two evaporation systems. In the device shown in Fig.9, the crucible of In and the crucible of Sb and the temperature of the substrate can be controlled independently, and each can be controlled under optimal conditions. The substrate temperature is controlled under the condition that InSb does not pyrolyze, and the temperature of the crucible of In and Sb is controlled so that the adhesion probability of In and Sb on the substrate surface is the same.

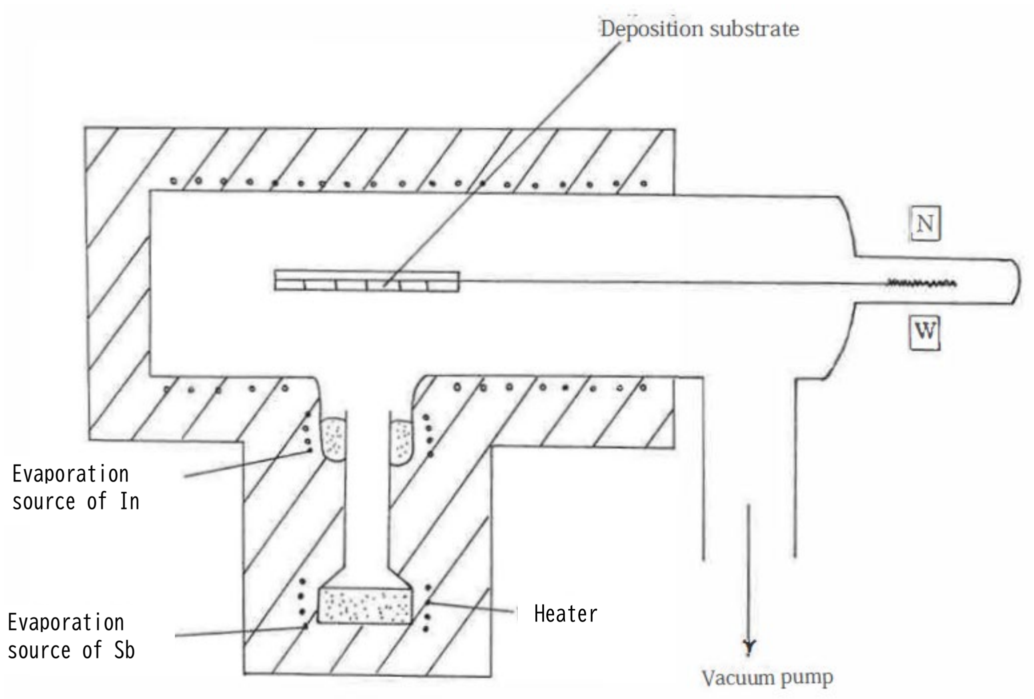

Fig.9 Gunther's three-temperature treatment equipment

The third method to obtain a deposition film with high electron mobility of InSb is the flash deposition method, in which fine particles of InSb are dropped during a high-temperature boat and evaporated instantaneously. In this method, the atoms of In and Sb reach the same number of substrates in a very short time. However, if the substrate temperature is not set so that In and Sb are identical on the substrate, it is not possible to obtain a film with a stoichiometric composition. However, in general, this substrate temperature is not always suitable for crystal growth, so it is difficult to increase the electron mobility. However, in the sense of obtaining a 1:1 composition of In and Sb, it is a simple and sophisticated method. In this case, it may be necessary to use heat treatment to increase the electron mobility after deposition.

The fourth method for obtaining high electron mobility thin films of InSb is to use several boats as evaporation sources to achieve stoichiometric composition and high electron mobility by optimally controlling the substrate temperature by repeating the simple deposition method mentioned above, and to evaporate InSb instead of Inn and Sb alone by improving the three-temperature method.

Both operations are complex operations, but they are chemically theoretical, and films with high electron mobility can be obtained. It is relatively easy to obtain electron mobility of 20,000 or more within a thickness of 1 μm. The deposition film obtained by the method described above is a thin film of polycrystalline InSb, which is usually about 1 μm when used for Hall devices, and the electron mobility exceeds 30,000 cm^2/V• sec at room temperature.

The conductive type is a true semiconductor that exhibits n-type conductivity unless it is doped with anything.

The most important factors in InSb deposition are the purity of the InSb used for the evaporation source and the surface condition of the substrate. The InSb used during evaporation should be as high purity as possible, and it is desirable to use at least 7-9 non-Dope InSb. If In and Sb are evaporated from separate boats, the purity of In and Sb must be high.

As a substrate for deposition, it is necessary to be stable at a high temperature of 400~600°C, without the risk of impurities being released or decomposed by heating, and with a smooth surface and insulating properties. Therefore, substrates such as quartz glass, ceramics, and ferrites, and mica and other natural products are used. In many cases, it is used as a deposition plate after surface treatment with appropriate insulation properties on the surface. In addition, it is of course desirable for the improvement of thin film properties to have a smooth mirror surface for surface roughness.

Next, let's look at the characteristics of the InSb deposition film obtained in this way. Fig. 10 shows the temperature dependence of the resistivity of an InSb deposition film with a thickness of 1.0μm. The horizontal axis is the reciprocal of the absolute temperature. It is very good to go on a straight line. Fig.11 shows the temperature dependence of the electron mobility of the same deposition film.

As you can see from this figure, the electron mobility does not change much around room temperature. At low temperatures, the electron mobility tends to decrease slightly, but this property is different from that of non-dope single crystals, and because it is polycrystalline, it indicates the existence of a dominant scattering factor at low temperatures.

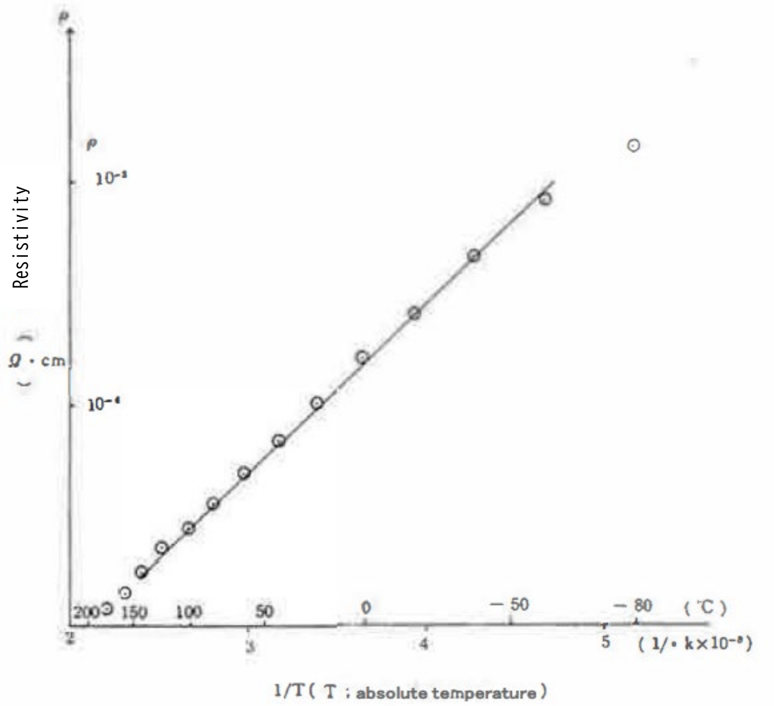

Fig. 10 Temperature-dependent resistivity of In Sb deposition films. ρ (Ω m).

Furthermore, the temperature characteristics of this electron mobility near room temperature are expected to have good temperature characteristics of Hall voltage compared to Equation (2) when a constant voltage input is applied to the vapor deposition element. On the other hand, in the case of constant current drive, as can be seen from Equation (1), the Hall output is proportional to the Hall coefficient, so it does not show the low temperature dependence as described above.

$$V_H = R_H \frac{I \cdot B}{d} \quad (1)$$

$$V_H = \mu_H \frac{w}{l} V_{in} \cdot B \quad (2)$$

These InSb deposition films are n-type at room temperature, and their semiconductor properties are not lost even at 200°C. Even if a thermal shock exceeding 200°C is subjected to it, the properties of the semiconductor remain unchanged.

Fig.12 shows the temperature dependence of the Hall coefficient. Hall coefficient R_H, electrical conductivity σ and electron mobility μ_H

$\mu_H = R_H \cdot \sigma$

The large temperature dependence of R_H is due to the large temperature dependence of electrical conductivity ($1/\sigma$ is the resistivity).
This temperature dependence is due to the increase in electron concentration with increasing temperature.

The difference in temperature characteristics between μ_H and R_H described here gives the difference in temperature characteristics of the Hall output voltage in Equations (1) and (2) when the Hall element is fabricated. In this way, if the thickness of the InSb deposition film is 1 μm, the input resistance of the Hall element can be designed to be several hundred ohms, and a Hall element that can be used by the constant voltage input of the Hall element can be easily created. In addition, due to its high sensitivity, it has the advantage of low drive current and extremely low power consumption of the Hall element. This is an excellent property that other materials cannot match at all.

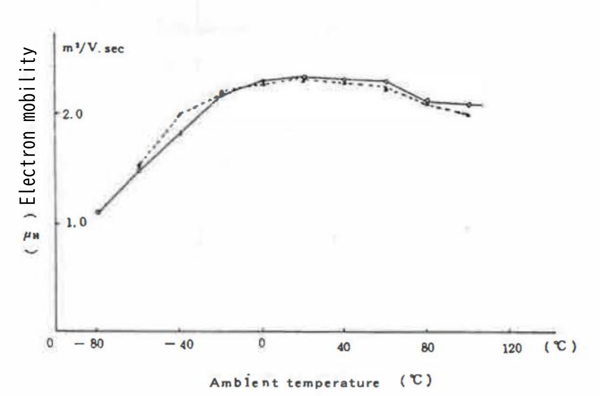

Fig. 11 Temperature dependence of electron mobility of InSb deposition films.

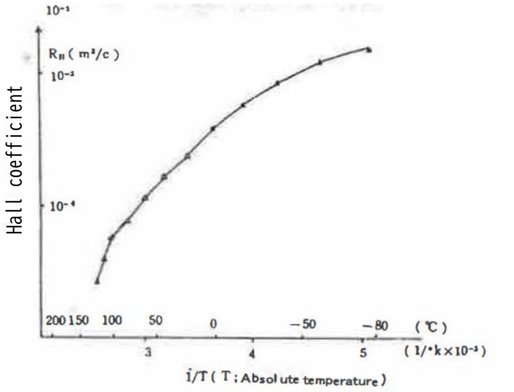

Fig. 12 Temperature dependence of Hall coefficient of InSb deposition films.

Section 5. Basic characteristics of deposition Hall elements

There are two types of InSb Hall devices, as described in Section 3. The most basic ones are those with structures fabricated on non-magnetic substrates such as ceramics. Furthermore, the most important Hall device in practical use is the one that has been made highly sensitive by magnetic amplification by magnetic materials.

Table 1 shows examples of the basic characteristics of practical vapor deposition Hall elements. In addition, the maximum rating value is shown in Table 2. Fig.13 shows the outline diagram.

Table 1 Characteristics of InSb vapor deposition Hall elements (Asahi Kasei HL-300 C, H-300 A)

	symbol	min.	max.	unit	condition
(1) HL-300C Hall Element Hall voltage of (ceramic substrate)	V_H	31 41 51	45 57 74	mV	Vin=1 V B=500 G
(2) H-300 A-Hall element Hall voltage (magnetically amplified)	V_H	68 78 91 106 123	82 95 110 127 150	mV	Vin=1V B=500 G
Input Resistance Output resistance	Rin Rout	240 240	~ 550 ~ 550	Ω Ω	
Unbalanced voltage	Vu	$V_u/V_H \leqq$ less than ±5%			B=0 B=500G

Table 2 Maximum rating of the Ion nSb deposition Hall element (Asahi Kasei HL-300 C, H-300 A)

	symbol	Rated value	unit	condition
Maximum control current	Ic max	20	mA	40°C
Maximum Input Voltage	Vin max	2.0	V	40°C
Operating temperature		-20 ~ +100	°C	
Storage temperature		-40 ~ +110	°C	

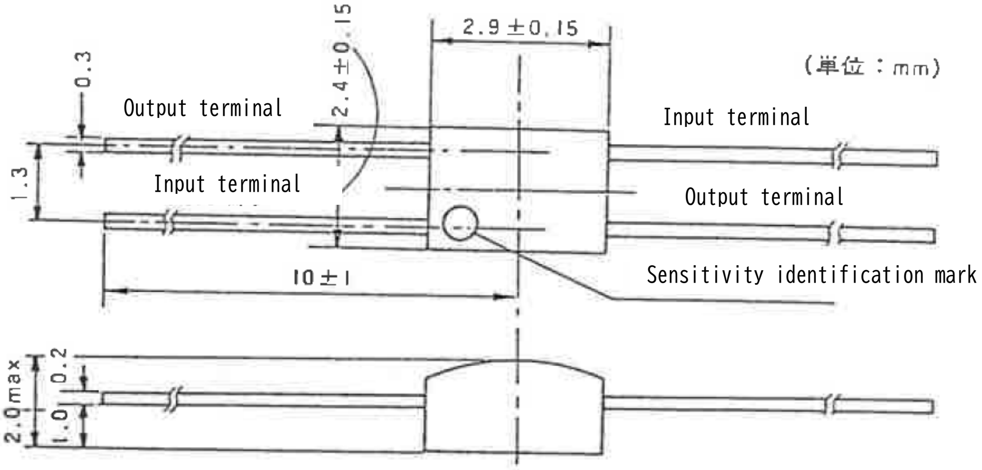

Fig. 13 Hall element outline diagram (HL-300 C, H-300 A Hall element)

Here, HL-300C is a Hall element with the basic structure of Fig. 6 (a), and H-300A is a magnetically amplified Hall element with the structure of Fig. 6 (b). Now, the sensitivity of the Hall element is shown by the value of Hall voltage VH at an input voltage of 1V and a magnetic flux density of 500G. The value of the unbalanced voltage Vu is expressed as the voltage between the output terminals when the input is 1 V and the magnetic flux density B = 0. In this example, the unbalanced voltage is extremely small compared to the Hall voltage VH, and the value of [Vu/VH (B=500G)] is within 5%. The reason for this small value is that in the case of InSb deposition Hall elements, the sensitivity (Hall output voltage VH) is large, the film thickness is very thin, the film thickness is 0.8~1.0μm, and photoetching is easy, so the pattern formation accuracy of the Hall element is good, and the unequilibrium voltage Vu can be kept small. In the practical Vapor Deposition Hall element with the structure shown in Section 3, Fig. 6(b), the value of Hall voltage VH is approximately three times larger than that without magnetic amplification due to magnetic amplification by ferrite. On the other hand, the proportional range of Hall voltage relative to the magnetic flux density is limited. However, since the analog output is sufficient at magnetic flux densities of 1 K.G or less, which are usually used very often, there is no practical hindrance.

Now, the maximum rated value of the Hall element is important in the sense of determining the maximum value of Hall voltage VH from the practical Hall element, and both Vin max and Ic max are shown in Table 2.